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Characterisation of processed drill cuttings from the TCC RotoMill-process

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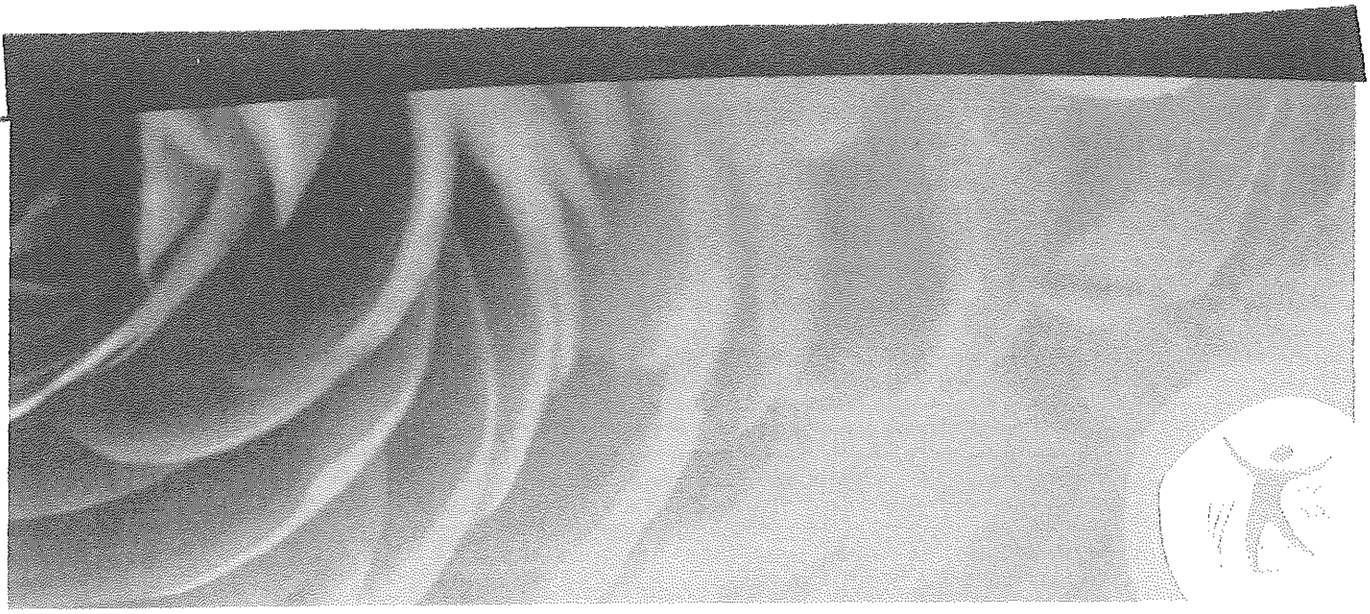

Hovedkontor/Head office
Frederik A. Dahls vei 20
N-1432 Ås
Tel.: (+47) 40 60 41 00
post@bioforsk.no

Bioforsk Jord og miljø
Frederik A. Dahls vei 20
N-1432 Ås
Tel.: (+47) 40 60 41 00
carl-einar.amundsen@bioforsk.no

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Author(s): Carl Einar Amundsen and Roald Sørheim			
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Summary:
TWMA intends to apply for end of waste certification for its processed drill cuttings (here designated Solids from the TCC RotoMill process). In order to demonstrate that the processed drill cuttings meet the legal test for end of waste, TWMA needs to show that they are capable of being used in the same way as an equivalent non-waste product, and with no worse environmental effects.

In this report the total and leachable content of the Solids from the TCC RotoMill process are summarized. Based upon the leachable amount of contaminants, potential toxicological effects are discussed.

Possible reuse options are briefly discussed.

Approved

Øistein Vethe

Project leader

f/ Carl Einar Amundsen

1. Summary

Background

TWMA intends to apply for end of waste certification for its processed drill cuttings (here designated Solids from the TCC RotoMill process). In order to demonstrate that the processed drill cuttings meet the legal test for end of waste, TWMA needs to show that they are capable of being used in the same way as an equivalent non-waste product, and with no worse environmental effects. The total content in Solids from the TCC RotoMill process are compared with mean values for Norwegian agricultural soils, Norwegian overbank sediments and with Norwegian Soil Quality classes. Agricultural soils and overbank sediments are considered as suitable non-waste comparators for the Solids from the TCC RotoMill process.

The analysis of dry matter and leaching tests that have been performed on the Solids from the TCC RotoMill process agrees with the demands for basic characterisation of waste prior to landfilling. The leaching tests also agree with the demands for on-site verification.

The analysis of dry matter and leaching procedures performed also give information about the physical and chemical properties of the Solids from the TCC RotoMill process necessary for evaluating the re-use options of the treated drill cuttings.

Total content

The Solids from the TCC RotoMill process are characterised by high pH (10-12), high levels of chloride, sulphate, barium and hydrocarbons with chainlength C16-C35. All these parameters are much higher in the Solids than in Norwegian soils.

The mean and maximum concentrations of cadmium, lead, mercury, copper, nickel, chromium and zinc, arsenic, polycyclic aromatic hydrocarbons (PAH), are comparable with the content in Norwegian soils and overbank sediment.

The present information on the Solids, however, does not indicate that the Solids from the TCC RotoMill process have particular liming or nutrient properties. To evaluate the nutrient and liming potential of the Solids, more specific extractions, as well as pot experiments involving plant growth, has to be performed.

The particle size distribution of some Solids, show that they mainly consist of silty material (particle size 2-63 µm, 50-70%), 5-15% clay (<2 µm) and 20-40% of sand (60-2000) (silty loam). A high fraction of silt (and some clay), results in high water holding capacity.

The specific surface area was determined to 1.61 m^2/g in one Solid sample, which indicate relatively low sorption capacity. Specific surface area of the Solids will vary depending on type of rock formation.

Leaching

Leaching to surface and groundwater water is one of the major environmental concerns when using Solids from the TCC RotoMill process as filler- or construction material (or other applications).

The leaching tests (batch extraction test and column leaching test) show that the content of dissolved organic carbon (DOC) exceed the limit set for landfills for hazardous waste. The content of DOC make treatment necessary prior to landfilling The content of the other parameters in the eluate make disposal on landfills for non-hazardous waste possible.

Toxicity of leachate from Solids from the TCC RotoMill process

Based upon comparison of eluate concentrations from the batch extraction test (LS10) with PNEC-values, the detrimental biological effects due to runoff are probable. In most cases, however, the dilution of runoff or seepage from Solids from the TCC RotoMill process is much higher than 10 (which is the ratio between extraction agent (water) and Solid material in the batch extraction test).

Another important factor is that the eluate from the solids from the TCC RotoMill process contain both high concentrations of calcium and dissolved organic carbon, probably resulting in significantly reduced toxicity.

Barium is present in Solids from the TCC RotoMill process as $BaSO_4$ which is not soluble in water. It is therefore highly unlikely that barium, both in the Solids and in the leachates, will cause any toxicity to organisms in soils and water.

Monitoring at disposal sites for Solids from the TCC RotoMill process

Three categories of parameters should be included in monitoring programmes were Solids from the TCC RotoMill process are involved: 1) parameters that exceed the PNEC-values; 2) parameters having high concentrations in eluates from leaching tests relative to concentrations in natural waters; 3) parameters that normally are not present in waters.

The following parameters should be included in monitoring programmes: pH, Conductivity, Dissolved organic carbon (DOC), Arsenic, Copper, Chromium, Nickel, Barium, Chloride, Sulphate, Fluoride, Hydrocarbons (C10-C35) and Phenols (Phenol Index).

Re-use options for Solids from TCC RotoMill process

Based upon available information on the chemical and physical properties of Solids from the TCC RotoMill process, the Solids may be suitable for use in growing media and filling materials. A relatively low content of clay probably make the hydraulic conductivity to high and the Solids unsuitable as a liner material at landfills.

Prior to any application of treated drill cuttings, a risk evaluation has to be performed. The evaluation should include possible positive and the negative aspects of the application.

2. Introduction

The waste considered in this project is recovered solids from the treatment of oil contaminated drilling wastes via the TCC RotoMill process. In this report this waste is termed "Solids from the TCC RotoMill process".

The total content of Solids from the TCC RotoMill process is available through three different sampling and analysis regimes (Table 1). The results presented in this report are from these three samplings.

Table 1: Overview of sampling programmes, number and type of analysis in each programme, and parameters determined.

Category of sampling	Description	Analysis		
		Total solids	Leaching test	
			Batch	Column
Monthly sampling	Random monthly sample of Solids from the TCC RotoMill process	23	5	2
TWMA samples 100g	Composite sample taken during one week from Solids from the TCC RotoMill process	15	0	0
TWMA samples 50g	Random sample collected for every 25tons of processed Solids from the TCC RotoMill process	60	0	0
	Parameters			
Monthly sampling	Heavy metals (23), oil in sand (hydrocarbons, 23), PAH (3), PCB (1),			
TWMA samples 100g	Heavy metals (15), PAH (15), cyanide (15), sulphate, sulphide, phenolindex (15), ammonium (6), chloride (6) selenium (13), bromide (3)			
TWMA samples 50g	Oil in sand (hydrocarbons, 60), PAH (60)			

In principle there should be no difference between the three sampling regimes when it comes to the composition of Solids from the TCC RotoMill process. The TWMA samples 50g, however, probably give the most representative data for oil in sand (hydrocarbons) and PAH, while the monthly sampling and TWMA samples 100g give the only data for heavy metals (38 samples altogether).

The Solids from the TCC RotoMill process are reused as a fill material within the development of a future industrial facility. Possible environmental impacts following this practice will not be discussed in this report.

3. Composition of treated drill cuttings (TCC RotoMill-process)

3.1 Total content

Results for single samples are not considered in this project. The focus has been on presenting summary statistics i.e. minimum, mean, median and maximum values, as well coefficients of variation, for the different parameters.

The total content in Solids from the TCC RotoMill process are compared with mean values for Norwegian agricultural soils (Esser 1996), Norwegian overbank sediments (Ottesen et al. 2001) and with Norwegian Soil Quality classes (Klif 2009).

Agricultural soils and overbank sediments are considered as suitable non-waste comparators for the Solids from the TCC RotoMill process. Comparison with Norwegian Soil Quality Classes relates the composition of the solids to Norwegian legislation and to possible applications of the solids. Soil within Quality class I is considered non-polluted (clean, Norwegian Reference values), while soils within class II are slightly polluted. Soils within class I and II are legal within kindergartens, in private gardens and playgrounds. Class III soils are allowed in rural areas, class IV soils in industrial areas, while soils above class V are considered toxic waste and should be removed immediately and deposited on toxic waste sites.

One important question in this context is in what context high single values are important. When the Solids from the TCC RotoMill process are used as a filler or bulking agent in construction/land engineering sector (involving tens or hundreds of loads), single loads containing elevated concentrations will have no negative environmental effect. At smaller locations, however, the environmental consequences may be detectable.

3.1.1 Heavy metals

The mean values for arsenic, cadmium, lead, chromium, copper, nickel, zinc and mercury are all below the limit for Quality class I. The mean concentration for copper in the Solids is two-three times higher the mean concentration in soils and overbank sediments, but still within what could be found in an unpolluted soil. The maximum values for all elements are within class II i.e. the Solids from the TCC RotoMill process can be used within kindergartens, in private gardens and playgrounds.

The concentration of barium in the Solids from the TCC RotoMill process is much higher (20-25 times) than what could be found in natural soil (the mean concentration of Barium in the earth crust is 250 mg/kg).

The results from the analysis of the TWMA samples 100g (weekly composite samples) (Table 4) leads to more or less the same conclusions: the Solids from the TCC RotoMill process can, based upon the content of heavy metals and arsenic, be used in kindergartens, private gardens and playgrounds. In the TWMA 100g samples the maximum concentration of arsenic slightly exceeds class II limit value.

The concentrations of boron in the Solids from the TCC RotoMill process are somewhat higher than is expected in Norwegian soils, but both is within what could be found naturally. The concentrations of sulphur are 5-10 times what is considered normal in soils (see Table 2, overbank sediments).

Table 2: Concentrations of heavy metals in soils and Norwegian Quality classes for soils. Unit: mg/kg.

			Soil Quality Class¤				
Parameter	Agr.soil* (0-5 cm)	Overbank sediments#	I	II	III	IV	V
Iron		24400					
Sulfur		600					
Copper	19,2	22	100	100-200	200-1000	1000-8500	8500-25000
Zinc	63,9	54	200	200-500	500-1000	1000-5000	5000-25000
Lead	23,9	22	60	60-100	100-300	300-700	700-2500
Cadmium	0,22		1,5	1,5-10	10-15	15-30	30-1000
Vanadium		41					
Nickel	21,1	22	60	60-135	135-200	200-1200	1200-2500
Chromium	27,1	32	50	50-200	200-500	500-2800	2800-25000
Molybdenium		2,2					
Arsenic		4	8	8-20	20-50	50-600	600-1000
Chloride		183					
Mercury	0,047		1	0-1	1-4	4-10	10-1000
Sum PCB7			0,01	0,01-0,5	0,5-1	1-5	5-50
DDT			0,04	0,04-4	4-12	12-30	30-50
Sum PAH16			2	2-8	8-50	50-150	150-2500
Naphtalene			0,8				
Fluorene			0,8				
Fluorantene			1				
Pyrene			1				
Benzo(a)pyrene			0,1				
Toluene			0,3				
Hydroc C5-C6			7				
Hydroc C-C8			7				
Hydroca C8-C10			10	≤10	10-40	40-50	50-20000
Hydroc >C10-C12			50	50-60	60-130	130-300	300-20000
Hydroc>C12-C35			100	100-300	300-600	600-2000	2000-20000
DEHP			2,8	2,8-25	25-40	40-60	60-5000

*Esser (1996); #Ottesen et al. (2001); ¤Klif 2009.

Table 3: Statistical data for Soilds from the TCC RotoMill process. ***Monthly samples.***

Element	Unit	n	Min	Mean	Median	Max	CV
Arsenic	mg/kg	22	2,9	8	9	12	25
Barium	mg/kg	22	700	5980	6150	17000	61
Cadmium	mg/kg	23	0,2	1	0,4	3	222
Chromium	mg/kg	22	25	35	34	81	31
Copper	mg/kg	23	39	54	53	73	16
Molybdenium	mg/kg	22	0,9	3	3	14	102
Nickel	mg/kg	23	18	33	35	48	23
Lead	mg/kg	23	13	29	26	89	100
Tin	mg/kg	22	0,2	0,5	0,3	1	120
Vanadium	mg/kg	4	23	35	32	52	29
Zinc	mg/kg	23	53	115	81	470	111
Mercury	mg/kg	23	0,0	0,1	0,1	0,21	75

Table 4: Statistical data for Soilds from the TCC RotoMill process. ***TWMA samples 100g.***

Element	n	Min	Mean	Median	Max	CV
Copper	15	37	58	46	130	42
Arsenic	15	6,6	14	13	21	33
Lead	15	22	33	28	60	35
Iron	6	28000	34833	34000	41000	15
Cadmium	12	<0,1	0,3	0,255	1	85
Chromium	15	21	50	40	84	42
Nickel	15	18	38	37	61	40
Zinc	15	46	92	85	170	33
Mercury	15	<0,1	4,9	0,1	69	365
Boron	15	18	58	45	110	58
Calcium	6	22000	32333	32500	40000	22
Sulphur	11	3000	8755	4300	29000	94

3.1.2 *Organic components*

It is not yet clear what hydrocarbons the "Oil in sand" analysis involves, but most probably it includes hydrocarbons C10-C40 i.e. it is equivalent to the analysis hydrocarbons C10-C35 (Table 6).

The concentration of oil (hydrocarbons) in the Solids from the TCC RotoMill process is relatively high (Quality Class IV). In organic rich soils some hydrocarbons are present, but at much lower concentrations.

Table 5: Concentrations of hydrocarbons in monthly random samples.

	Enhet	n	Min	Mean	Median	Max
Oil in sand	mg/kg	23	73,0	1221	1100	2600

PCB-7 was not detected in the random sample collected in the period 4-11.May 2011 (Table 6).

Table 6: Concentrations of organic contaminants in Solids from the TCC RotoMill process. ***Random samples 2011.***

Parameter	Unit	4-11/5 2011	05.July 2011-I	05.July 2011-II
PCB 28	mg/kg	<0,0030		
PCB 52	mg/kg	<0,0030		
PCB 101	mg/kg	<0,0030		
PCB 118	mg/kg	<0,0030		
PCB 138	mg/kg	<0,0030		
PCB 153	mg/kg	<0,0030		
PCB 180	mg/kg	<0,0030		
Sum PCB-7	mg/kg	<0,0030		
Naphtalene	mg/kg	0,031	0,22	0,11
Acenaphtylene	mg/kg	<0,010	<0,050	<0,050
Acenaphtene	mg/kg	<0,010	<0,050	<0,050
Fluorene	mg/kg	0,013	<0,050	<0,050
Phenanthrene	mg/kg	0,113	0,071	<0,050
Anthracene	mg/kg	0,014	<0,050	<0,050
Fluoranthene	mg/kg	0,025	<0,050	<0,050
Pyrene	mg/kg	0,066	0,067	<0,050
Benzo(a)anthracene	mg/kg	0,013	<0,050	<0,050
Chrycene	mg/kg	0,031	<0,050	<0,050
Benzo (b)fluoranthene	mg/kg	0,034	<0,050	<0,050
Benzo (k)fluoranthene	mg/kg	0,012	<0,050	<0,050
Benzo (a) pyrene	mg/kg	0,018	<0,050	<0,050
Dibenzo(ah)anthracene	mg/kg	<0,010	<0,050	<0,050
Benzo(ghi)perylene	mg/kg	0,07	<0,050	<0,050
Indeno(1,2,3-cd)pyrene	mg/kg	<0,010	<0,050	<0,050
Sum 16PAHs	**mg/kg**	**0,44**	**0,358**	**0,11**
Benzene	mg/kg	<0,0050		
Total extractable matter with toulen	mg/kg		340	1200
Total extract. matter with cyclohexane	mg/kg		2810	2510
Hydrocarbon C5-C6	mg/kg	<7		
Hydrocarbon >C6-C8	mg/kg	<7		
Hydrocarbon >C8-C10	mg/kg	<10		
Hydrocarbon >C10-C12	mg/kg	12		

Hydrocarbon >C12-C16	mg/kg	460		
Hydrocarbon >C16-C35	mg/kg	2450		
Tri-chloro ethene	mg/kg	<0,010		
Di-(2-ethylhexyl)phtalate (DEHP)	mg/kg	0,8		
Phenol index	mg/kg	3,86		
o,p-DDT	mg/kg	<0,010		
p,p-DDT	mg/kg	<0,010		

The analysis of hydrocarbons C5-C40 (Table 6) show that the majority of hydrocarbons are long chained (>C16). These are probably less water soluble and toxic than the "lighter" hydrocarbons (<C16).

Table 7: Summary statistics for PAH-16 and extractable matter with toluene and cyclohexane. TWMA samples 100g.

		n	Min	mean	Median	Max	CV
Naphtalene	mg/kg	15	<0,05	0,3	0,1	1,7	160
Acenaphtylene	mg/kg	15	<0,01	0,0	0,05	0,15	65
Acenaphtene	mg/kg	15	<0,01	0,1	0,05	0,15	70
Fluorene	mg/kg	15	<0,01	0,0	0,05	0,15	64
Phenanthrene	mg/kg	15	<0,05	0,1	0,09	0,25	56
Anthracene	mg/kg	15	<0,05	0,1	0,05	0,15	46
Fluoranthene	mg/kg	15	<0,05	0,1	0,05	0,15	49
Pyrene	mg/kg	15	<0,05	0,1	0,05	0,15	50
Benzo(a)anthracene	mg/kg	15	<0,05	0,1	0,05	0,2	66
Chrycene	mg/kg	15	<0,05	0,1	0,05	0,18	61
Benzo (b)fluoranthene	mg/kg	15	<0,05	0,1	0,05	0,44	120
Benzo (k)fluoranthene	mg/kg	15	<0,05	0,1	0,05	0,15	46
Benzo (a) pyrene	mg/kg	15	<0,05	0,1	0,05	0,16	58
Indeno(1,2,3-cd)pyrene	mg/kg	15	<0,05	0,1	0,05	0,29	88
Dibenzo(ah)anthracene	mg/kg	15	<0,05	0,1	0,05	0,15	45
Benzo(ghi)perylene	mg/kg	15	<0,05	0,1	0,07	0,62	120
Sum PAHs16	**mg/kg**	**15**	**0,065**	**1,0**	**0,266**	**3,28**	**112**
Total extractable matter with toulen	mg/kg	14	100	1715	895	5425	101
Total extractable matter with cyclohexane	mg/kg	15	120	1543	1600	4130	77

The content of hydrocarbons <C12 are within class I soils in the Norwegian classification system for soils (Table 6). Most samples of Solids from the TCC RotoMill process are however within class IV, making long-chained hydrocarbons one important parameter to include in a monitoring programme.

The mean value of sum PAH-16 in TWMA samples 100g (Table 7) is well below the Norwegian reference value (Quality class I) and must be considered low. Three out of 15 samples are higher than 2 mg/kg, but well within Quality class II.

Low concentrations of PAH was found in the TWMA samples 50g (Table 8). The mean value (0,33 mg/kg) is comparable with the natural background concentration of PAHs in soils.

The content of oil (hydrocarbons) in the Solids from the TCC RotoMill process are much higher than in soils.

The total organic matter content (loss on ignition, wt%) is below 10% in all samples. The limit value set for inert landfills is 3% TOC. A mean value of 6,8 on loss on ignition (Table 8), will result in a TOC in the range 3-4 % i.e. slightly above the limit value for inert waste landfills.

Table 8: Summary statistics for PAH-16 and extractable matter with toluene and cyclohexane (oil in sand). TWMA samples 50g (sample for every 25tons processed material).

	Enhet	n	Min	Mean	Median	Max	CV
Naphtalene	mg/kg	58	<0,01	0,1	0,145	0,72	102
Acenaphtylene	mg/kg	58	<0,01	0,1	0,01	0,15	107
Acenaphtene	mg/kg	58	<0,01	0,1	0,02	0,15	105
Fluorene	mg/kg	58	<0,01	0,1	0,01	0,15	107
Phenanthrene	mg/kg	60	<0,01	0,1	0,05	0,15	70
Anthracene	mg/kg	60	<0,01	0,1	0,01	0,15	110
Fluoranthene	mg/kg	60	<0,01	0,1	0,02	0,15	95
Pyrene	mg/kg	60	<0,01	0,1	0,04	0,15	83
Benzo(a)anthracene	mg/kg	60	<0,01	0,1	0,01	0,15	107
Chrycene	mg/kg	60	<0,01	0,1	0,03	0,15	90
Benzo (b)fluoranthene	mg/kg	60	<0,01	0,1	0,03	0,15	93
Benzo (k)fluoranthene	mg/kg	60	<0,01	0,1	0,01	0,15	109
Benzo (a) pyrene	mg/kg	60	<0,01	0,1	0,045	0,15	90
Indeno(1,2,3-cd)pyrene	mg/kg	60	<0,01	0,1	0,01	0,15	109
Dibenzo(ah)anthracene	mg/kg	60	<0,01	0,1	0,01	0,15	111
Benzo(ghi)perylene	mg/kg	60	<0,01	0,1	0,03	0,17	90
Sum PAHs16	**mg/kg**	**38**	**0,038**	**0,3**	**0,257**	**1,77**	**101**
Oil in sand	mg/kg	60	79	1840	960	16000	135
Organic matter	wt%	60	4	6,8	7	9	15

3.1.3 Other parameters

The Solids from the TCC RotoMill process are characterised by a high pH and conductivity, and high content of chloride and sulphate, far higher than in Norwegian soils. Also the content of Bromine is higher than in soils.

The content of ammonium and selenium are within normal values for Norwegian soils.

Cyanide (free and total) has not been detected in any of the Solids from the TCC RotoMill process (Table 9).

There is no particular information on the nutrient content of the Solids. XRF-analyses show that the total content of P_2O_5 varies in the range 0.1-0.14%, which are typical for soils. Information on the content of nitrogen is not available, but it is unlikely that there are plant available nitrogen present in the Solids.

The content of CaO varies from 7.2-9.5% in the same XRF-analysis. The liming potential of CaO (and MgO, K_2O etc) depends on the solubility of these oxides. pH above 7 in the leaching tests show that the Solids results in basic pH in water, but the liming potential in soils have to be decided by experiments.

To evaluate the nutrient potential, more specific extractions, as well as pot experiments involving plant growth, has to be performed. The present information on the Solids, however, does not indicate that the Solids have particular liming or nutrient properties.

The particle size distribution of some Solids, show that they consist of 50-70 % silty material (particle size 2-63 µm), 5-15 % clay (<2 µm), and 20-40 % of sand (60-2000 µm). The mean diameter (D(v, 0.5)) in four samples of Solids were 8, 10, 14 and 32 µm. In a soil terminology, the Solids in most cases are characterised as silty loam. A high fraction of silt (and some clay), results in high water holding capacity.

In one of the analysis (D(v, 0.5)=14 µm), the specific surface area was 1.61 m^2/g, which is in the kaolinitt (1:1 clay mineral) range. The sorption capacity of this Solid therefore is relatively low compared to 2:1 clay minerals and organic matter.

Table 9: Summary statistics for various inorganic parameters and Phenol Index. TWMA samples 100g (weekly composite samples).

	Enhet	n	Min	mean	Median	Max	CV
Dry matter	wt%	6	91,7	98	99	100	3
pH	pH	15	10	11	11	12	6
Conductivity	µS/cm	6	286	1557	1925	2450	63
Ammonium	mg/kg	6	12	78	81	160	72
Phenolindexs	mg/kg	15	0,01	0,4	0,48	0,86	74
Chloride	mg/kg	6	11	4219	4950	5600	50
Selenium	mg/kg	13	0,14	2,6	<2	5	57
Bromine	mg/kg	3	130	463	430	830	76
Cyanid- free	mg/kg	15	<0,05	<0,1	<0,1	<0,1	19
Cyanid- total	mg/kg	15	<1	<1,0	<1	<1	0
Sulfate	mg/kg	15	61	23259	17000	80000	112
Sulfide	mg/kg	9	1,1	4,0	2	12	93

3.2 Leaching tests

Leaching tests have been performed on some monthly random samples. The tests involve a batch extraction procedure (solid:liquid ratio 10) and a column leaching test (saturated flow, analysis of the most concentrated eluate, LS 0,1).

These leaching tests are performed as major parts of procedures to characterise waste with respect to acceptability of waste at landfills. The procedure consists of the basic characterisation, compliance testing and on-site verification and the leaching tests are used in the basic characterisation (column leaching test, LS 0,1) and compliance testing (batch extraction test, LS 10).

3.2.1 Batch extraction (LS 10)

The batch leaching test show that it is only the content of dissolved organic carbon (DOC) in the LS 10-eluate that exceeds the limit value set for landfills for hazardous waste (Table 10). The content of the other parameters in the eluate make disposal on landfills for inert or ordinary waste possible.

Table 10: Summary statistics for results from batch extraction tests (LS10).Random samples. Green: landfill for inert waste; Blue; landfill for non-hazardous and hazardous and waste; Orange: landfill for hazardous waste

		Batch extraction test					
	Unit	n	Min	Mean	Median	Maks	CV
pH	pH	5	10,3	11	11,1	11,7	5
Conductivity	µS/cm	5	2650	3222	3160	3910	17
Chloride	mg/kg	5	500	5138	5730	7140	52
Fluoride	mg/kg	4	38	55,75	57	71	27
Sulfide	mg/kg	1	<0,4	0,4	0,4	0,4	
Sulfate	mg/kg	5	430	1986,2	990	6440	127
DOC	mg/kg	4	1260	1447,5	1445	1640	12
Phenol index	mg/kg	5	0,27	0,7002	0,42	1,7	83
Totalt dissolved solids	mg/kg	2	22000	23800	23800	25600	11
Arsenic	mg/kg	4	0,0261	0,051425	0,0498	0,08	54
Barium	mg/kg	2	1,62	3,83	3,83	6,04	82
Cadmium	mg/kg	2	<0,0005	<0,0005	<0,0005	<0,0005	0
Cobolt	mg/kg	1	0,0181	0,0181	0,0181	0,0181	
Chromium	mg/kg	5	0,0414	0,1039	0,118	0,137	36
Copper	mg/kg	5	0,357	0,591	0,616	0,863	37
Molybdenium	mg/kg	3	0,504	0,702	0,708	0,895	28
Nickel	mg/kg	5	0,413	0,7672	0,804	1,11	33
Lead	mg/kg	5	0,00216	0,009178	0,00312	0,0216	100
Vanadium	mg/kg	1	0,0679	0,0679	0,0679	0,0679	
Zink	mg/kg	5	<0,02	0,02888	0,0243	0,0557	52
Boron	mg/kg	2	4,19	8,245	8,245	12,3	70
Mercury	mg/kg	2	<0,0002	0,0002	0,0002	0,0002	0
Antimony		2	0,0108	0,01085	0,01085	0,0109	1
Selenium	mg/kg	5	0,0297	0,08234	0,057	0,152	62
Iron	mg/kg	3	0,069	1,043	1,21	1,85	86
KOF-Mn	mg/kg	3	370	427	450	460	12
Ammonium (NH4)	mg/kg	3	8,6	17	14	29	61
Cyanide-free	mg/kg	1	<1	<1	<1	<1	
Naphtalene	mg/kg	4	<0,002	0,01275	0,0125	0,024	71
Acenaphtylene	mg/kg	4	<0,0001	0,00505	0,00505	0,01	139
Acenaphtene	mg/kg	4	0,00016	0,0034	0,0002	0,01	164

Fluorene	mg/kg	4	<0,0001	0,00505	0,00505	0,01	139
Phenanthrene	mg/kg	4	<0,0001	0,00961	0,00019	0,038	197
Anthracene	mg/kg	4	<0,0001	0,00505	0,00505	0,01	139
Fluoranthene	mg/kg	4	<0,0001	0,00555	0,00555	0,011	139
Pyrene	mg/kg	4	<0,0001	0,01005	0,01005	0,02	140
Benzo(a)anthracene	mg/kg	4	<0,0001	0,00505	0,00505	0,01	139
Chrycene	mg/kg	4	<0,0001	0,00805	0,00805	0,016	140
Benzo (b)fluoranthene	mg/kg	4	<0,0001	0,00555	0,00555	0,011	139
Benzo (k)fluoranthene	mg/kg	4	<0,0001	0,00505	0,00505	0,01	139
Benzo (a) pyrene	mg/kg	4	<0,0001	0,00505	0,00505	0,01	139
Dibenzo(ah)anthracene	mg/kg	4	<0,0001	0,00505	0,00505	0,01	139
Benzo(ghi)perylene	mg/kg	4	<0,0001	0,00655	0,00655	0,013	139
Indeno(1,2,3-cd)pyrene	mg/kg	4	<0,0001	0,00505	0,00505	0,01	139
Sum PAHs16	mg/kg	4	0,0122	0,05283	0,0133	0,133	131
Sum PAH carcinogene	mg/kg	4	0,027	0,027	0,027	0,027	
PCB 28	mg/kg	1	<0,002	<0,002	<0,002	<0,002	
PCB 52	mg/kg	1	<0,002	<0,002	<0,002	<0,002	
PCB 101	mg/kg	1	<0,002	<0,002	<0,002	<0,002	
PCB 118	mg/kg	1	<0,002	<0,002	<0,002	<0,002	
PCB 138	mg/kg	1	<0,002	<0,002	<0,002	<0,002	
PCB 153	mg/kg	1	<0,002	<0,002	<0,002	<0,002	
PCB 180	mg/kg	1	<0,002	<0,002	<0,002	<0,002	
Benzen	mg/kg	1	<0,02	<0,02	<0,02	<0,02	
Toluen	mg/kg	1	<0,1	<0,1	<0,1	<0,1	
Ethylbenzen	mg/kg	1	<0,02	<0,02	<0,02	<0,02	
o-Xylen	mg/kg	1	<0,01	<0,01	<0,01	<0,01	
m/p-Xylener	mg/kg	1	<0,02	<0,02	<0,02	<0,02	
Xylener	mg/kg	1	<0,015	<0,015	<0,015	<0,015	
Fraksjon >C10-C12	mg/kg	1	84	84	84	84	
Fraksjon >C12-C16	mg/kg	1	129	129	129	129	
Fraksjon >C16-C35	mg/kg	1	289	289	289	289	
Fraksjon >C12-C35	mg/kg	1	418	418	418	418	
Fraksjon >C35-C40	mg/kg	1	24	24	24	24	
TOC	%	1	2,11	2,11	2,11	2,11	

3.2.2 *Column leaching test (LS 0,1)*

The results from the column leaching test also show that the Solids from the TCC RotoMill process have a leaching potential that for most parameters are in agreement with the limits set for landfills for inert waste. Only leaching of chloride and fluorine exceed the limit for inert landfills (Table 11).

Table 11: Results from column leaching tests of two random samples of Solids from the TCC RotoMill process collected 14.April and 19.July 2011.

	Enhet	14.April 2011	19.July 2011
pH	pH	10,9	10,8
Conductivity	µS/cm	43800	27100
Chloride	mg/kg	1180	848
Fluorine	mg/kg	0 - 0,0746	4,44
Sulfate (SO4)	mg/kg	142	88
DOC	mg/kg	160	106
Phenol Index	mg/kg	0,209	0,0353
Total diss. Soilds (TDS)	mg/kg	3760	
Arsenic	mg/kg	0,00205	0,00149
Barium	mg/kg	0,152	0,0187
Cadmium	mg/kg	0 - 0,0000298	0-0,0000202
Chromium	mg/kg	0,000587	0,000708
Copper	mg/kg	0,0101	0,0221
Molybdenium	mg/kg	0,0789	0,0877
Nickel	mg/kg	0,0484	0,0641
Lead	mg/kg	0,000586	0,00013
Vanadium	mg/kg		
Zinc	mg/kg	0,000449	0,000379
Boron	mg/kg		
Mercury	mg/kg	note	0-0,00000202
Antimony		0,000074	0,0000826
Selenium	mg/kg	0,00102	0,00322

4. Toxicity of Solids from the TCC RotoMill process

Results from leaching tests give a good indication on the amount of water soluble compounds in the Solids from the TCC RotoMill process. Concentrations in the eluate can not, however, be used in a directly comparison with biological effect concentrations in water. A comparison of the eluate concentrations from the leaching tests and effect concentrations, will however give an indication on what compounds could be a potential problem when using the Solids from the TCC RotoMill process.

4.1 Biological effect levels

Predicted No Effect Concentrations (PNEC) for a parameter is predicted from several biological tests on at least three trophic levels. Most of the PNECs are predicted using standard sensitivity distributions (SSD) and the calculated value is supposed to protect 95% of the species (HC5).

Comparison of the eluate concentrations with PNEC-values (Table 12) show that the potential for biological effects in nearby surface waters are largest due to fluoride, copper and nickel (Table 12). For all three elements the toxicity depends on the water softness (concentrations of e.g. calcium).

Also the concentrations of chloride, sulphate, arsenic, chromium and ammonium exceed the predicted PNEC-values, but to a lesser degree.

Table 12: Concentrations of inorganic and organic parameters in eluates from batch extraction tests (LS10). Green: concentrations lower than PNEC; Blue: concentrations <5 times PNEC; Orange: >5-10 times PNEC; Red: more than 10 times PNEC.

		PNEC	Not registered	Composite sample RC10 + RC4			
Parameter	Date		1.July 2010	13. April 2011	19. July 2011	05.July 2011	05.July 2011
pH	pH		11,1	11,3	10,6	11,7	10,3
Conductivity	µS/cm		2790	3600	3160	3910	2650
Chloride	mg/l	150	50	557	714	675	573
Fluoride	mg/l	0,4		3,8	4,9	6,5	7,1
Sulphate (SO4)	mg/l	100	644	43	137	70,1	99
DOC	mg/l			134	126	164	155
Phenol index	µg/l		27	170	40	71,1	42
Arsenic	µg/l	5	7	8	2,96	1	2,61
Barium	µg/l			604	162		
Cadmium	µg/l	0,08	<0,05	<0,05	<0,05	<0,05	
Cobalt	µg/l		1,81				
Chromium	µg/l	5	4,14	9,91	12,4	11,8	13,7
Copper	µg/l	7,8	38,4	35,7	61,6	86,3	73,5
Molybdenum	µg/l		50,4	70,8	89,5		
Nickel	µg/l	6	41,3	67,4	111	80,4	83,5
Lead	µg/l	2,5	1,65	0,312		2,16	0,216
Vanadium	µg/l		6,79				
Zinc	µg/l		2	2	2,43	5,57	2,44
Boron	µg/l		419				1230
Mercury	µg/l	0,05	<0,02	<0,02	<0,02	<0,02	<0,02
Antimony	µg/l	113		1,09	1,08		
Selenium	µg/l		2,97	5,7	11,8	5,5	15,2
Ammonium	mg/l	0,5	0,86			1,4	2,9
Cyanide-free	µg/l		<100			<10	<10
Naphtalene	µg/l	2,4	0,061			1,2	1,3
Acenaphtylene	µg/l	1,3	<0,01			<0,01	<0,01
Acenaphtene	µg/l	3,8	<0,02			<0,01	0,016
Fluorene	µg/l	2,5	<0,01			<0,01	<0,01
Phenanthrene	µg/l	1,3	<0,01			0,02	0,017
Anthracene	µg/l	0,11	<0,01			<0,01	<0,01
Fluoranthene	µg/l	0,1	<0,01			<0,01	<0,01
Pyrene	µg/l	0,023	<0,01			<0,01	<0,01

Benzo(a)anthracene	µg/l	0,012	<0,01			<0,01	<0,01
Chrycene	µg/l	0,07	<0,01			<0,01	<0,01
Benzo (b)fluoranthene	µg/l	0,03	<0,01			<0,01	<0,01
Benzo (k)fluoranthene	µg/l	0,03	<0,01			<0,01	<0,01
Benzo (a) pyrene	µg/l	0,05	<0,01			<0,01	<0,01
Dibenzo(ah)anthracene	µg/l	0,0014	<0,01			<0,01	<0,01
Benzo(ghi)perylene	µg/l	0,006	<0,01			<0,01	<0,01
Indeno(1,2,3-cd)pyrene	µg/l		<0,01			<0,01	<0,01
Sum PAHs16	µg/l		<0,02			1,22	1,33

The concentrations of PAHs in the eluates are all below PNEC and there is a low probability that these compounds will cause any detrimental biological effects in water bodies receiving runoff from areas containing Solids from the TCC RotoMill process.

4.2 Conclusions

Based upon comparison of eluate concentrations from the batch extraction test (LS10) with PNEC-values, the detrimental biological effects due to runoff are probable. In most cases, however, the dilution of runoff or seepage from Solids from the TCC RotoMill process is much higher than 10 (which is the ratio between extraction agent (water) and Solid material in the batch extraction test).

Another important factor is that the eluate from the Solids from the TCC RotoMill process contain both high concentrations of calcium and dissolved organic carbon, probably resulting in significantly reduced toxicity.

The ecological value and vulnerability are other factors that need to be considered in a monitoring programme.

5. Re-use options for Solids from TCC RotoMill process

5.1 Growth media

Ecotoxicological tests involving e.g. plants and earthworms have shown treatment of oil based drill cuttings significantly reduce negative effects on these organisms. The results from these experiments indicate that a relatively high amount of Solids from the TCC RotoMill process can be used in soil or growth media without negative effects.

The positive effect of the Solids from the TCC RotoMill process are first of all related to the high silt content which will increase the water holding capacity of a soil mixture or growth media. The nutrient content is low, but there may be (generally) some liming capacity in the Solids that can be exploited.

5.2 Filler material

As a filler material, either individually or mixed with other materials, the Solids from the TCC RotoMill process may increase the water holding capacity. Removal of salts from the drill cuttings will make the clay swell, but at the time of disposal this swelling have diminished. The Solids will, based upon the available information, be suitable as filler material.

5.3 Liner at landfills

The Solids from the TCC RotoMill process seem to have a lower content of clay (5-15%) than untreated drill cuttings (mean 20-30%; Amundsen and Sørheim 2006). The potential for using the Solids as a liner material at landfills therefore are reduced. Experiments have shown that the hydraulic capacity of some drill cuttings is lower than the limit set for bottom liners at landfills ($1.0*10^{-9}$ m/s) (Amundsen et al. 2007). The texture of the Solids from the TCC RotoMill process most likely do not fulfil these requirements.

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Prior to any application of treated drill cuttings, a risk evaluation has to be performed. The evaluation should include possible positive and the negative aspects of the application.

6. Parameters for future monitoring at land constructions

All parameters that exceed the PNEC-values should be included in future monitoring of water bodies receiving runoff from Solids from the TCC RotoMill process.

Also parameters having high concentrations in the eluates should be included. High concentrations mean high relative to concentrations in natural waters or parameters that normally are not present in waters (e.g. hydrocarbons and phenols).

Based upon this we suggest that the following list of parameters should be included in monitoring programmes:

pH

Conductivity

Dissolved organic carbon (DOC)

Arsenic

Copper

Chromium

Nickel

Barium

Chloride

Sulphate

Fluoride

Hydrocarbons

Phenols (Phenol Index)

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